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Docket No.: GR 00 P 16715

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By: Yonghong Chen Date: October 8, 2006

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
Before the Board of Patent Appeals and Interferences

Applic. No.	:	09/940,092 Confirmation No.: 5991
Inventor	:	Siegfried Kamlah
Filed	:	August 27, 2001
Title	:	Anti-Theft System for a Motor Vehicle and Method for Operating the Anti-Theft System
TC/A.U.	:	2635
Examiner	:	Kimberly Y. Jenkins
Customer No.	:	**24131**

REPLY BRIEF

Mail Stop Appeal Brief - Patents
Hon. Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

S i r :

In response to the *Examiner's Answer* dated August 9, 2006, kindly consider the following remarks:

Remarks:

Regarding the Examiner's arguments that the claims of the instant application are obvious over a combination of Kirchlinde et al. and Nysen et al., Applicant believes that Kirchlinde et al., which describes a known remote-controlled access control device in particular for a motor vehicle, would not be combined with Nysen et al., which describes an orthogonal circular polarized wave for a signal transmission.

Nysen et al. embodies a base station named as controller and at least a satellite station named as communicator. For that transmission signals are used, which can be modulated in many different ways also as polarized waves. Preferred transmission systems of Nysen et al. are mobile phone systems (see column 6, line 45 and following) and so-called toll collection systems (see column 5, line 30 and following). This known transmission system preferably operates at a frequency of 2.45 GHz (see column 1, lines 47-48). Regarding the toll collection system, a correlation to vehicle only can be seen as in vehicles at least one communicator is used, whose signals are transmitted to the base station. The signals are then used for determining the driven distance and the subsequently determined fee and also for determining the

identity of the vehicle. These applications of Nysen et al. also show that there is not the slightest hint that this known system also can be used for anti-theft systems of vehicles.

In this context, it is also important to recognize that the invention of the instant application operates at the lower frequency at approximately 125 KHz (see the last paragraph on page 10 of the specification). Therefore, there is no reason for one skilled in the art to use the content known from Nysen et al. especially for systems using 2.45 GHz, also for the development of anti-theft systems in vehicles, at a preferred frequency of 125 KHz. As a consequence, the anti-theft systems of the invention of the instant application are not obvious over Kirchlinde et al. in combination with Nysen et al. Furthermore, it is well known from the enclosed literature that polarized waves are utilized depending on the frequency range of the application. For Am and FM radio signals vertical waves are used and for higher frequency transmission systems proposed by Nysen et al. circular polarized waves are used preferably.

For the above reasons as well as the reasons presented in the Appeal Brief, the honorable Board is therefore respectfully urged to reverse the rejections of the Primary Examiner and to

remand the application to the Examiner with instructions to allow claims 1-7 and 11 under appeal.

Respectfully submitted,

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Polarization

From Wikipedia, the free encyclopedia

In electrodynamics, **polarization** (also spelled **polarisation**) is the property of electromagnetic waves, such as light, that describes the direction of their transverse electric field. More generally, the polarization of a transverse wave describes the direction of oscillation in the plane perpendicular to the direction of travel. Longitudinal waves such as sound waves do not exhibit polarization, because for these waves the direction of oscillation is along the direction of travel.

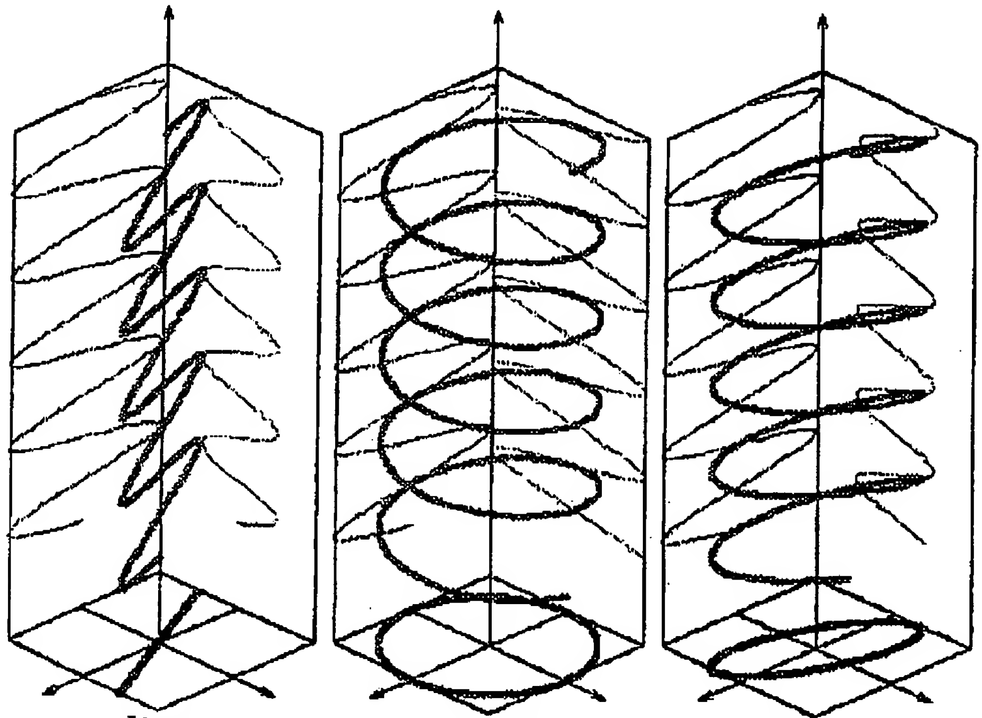
Contents

Theory

Basics - plane waves

The simplest manifestation of polarization to visualize is that of a plane wave, which is a good approximation to most light waves (a plane wave is a wave with infinitely long and wide wavefronts). All electromagnetic waves propagating in free space or in a uniform material of infinite extent have electric and magnetic fields perpendicular to the direction of propagation. Conventionally, when considering polarization, the electric field vector is described and the magnetic field is ignored since it is perpendicular to the electric field and proportional to it. The electric field vector may be arbitrarily divided into two perpendicular components labelled x and y (with z indicating the direction of travel). For a simple harmonic wave, where the amplitude of the electric vector varies in a sinusoidal manner, the two components have exactly the same frequency. However, these components have two other defining characteristics that can differ. First, the two components may not have the same amplitude. Second, the two components may not have the same phase, that is they may not reach their maxima and minima at the same time. The shape traced out in a fixed plane by the electric vector as such a plane wave passes over it (a Lissajous figure), is a description of the polarization state. The following figures show some examples of the evolution of the electric field vector (blue) with time (the vertical axes), along with its x and y components (red/left and green/right), and the path traced by the tip of the vector in the plane (purple):

In the figure on the left, the two orthogonal (perpendicular) components are in phase. In this case the ratio of the strengths of the two components is constant, so the direction of the electric vector (the vector sum of these



two components) is constant. Since the tip of the vector traces out a single line in the plane, this special case is called **linear polarization**. The direction of this line depends on the relative amplitudes of the two components.

In the middle figure above, the two orthogonal components have exactly the same amplitude and are exactly ninety degrees out of phase. In this case one component is zero when the other component is at maximum or minimum amplitude. There are two possible phase relationships that satisfy this requirement: the *x* component can be ninety degrees ahead of the *y* component or it can be ninety degrees behind the *y* component. In this special case the electric vector traces out a circle in the plane, so this special case is called circular polarization. The direction the field rotates in depends on which of the two phase relationships exists. These cases are called **right-hand circular polarization** and **left-hand circular polarization**, depending on which way the electric vector rotates.

All other cases, that is where the two components are not in phase and either do not have the same amplitude and/or are not ninety degrees out of phase are called **elliptical polarization** because the electric vector traces out an ellipse in the plane (the **polarization ellipse**).

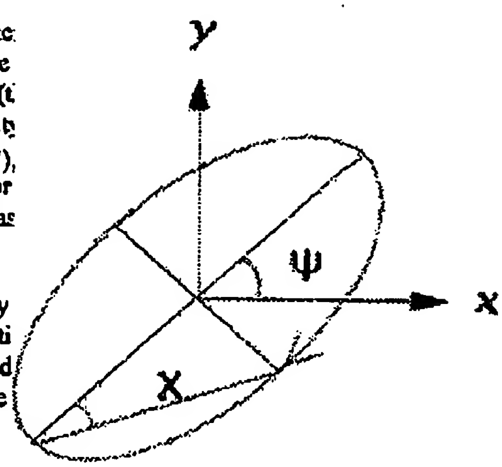
The "cartesian" decomposition of the electric field into *x* and *y* components is, of course, arbitrary. Plane waves of any polarization can be described instead by combining waves of opposite circular polarization, for example. The cartesian polarization decomposition is natural when dealing with reflection from surfaces, birefringent materials, or synchrotron radiation. The circularly polarized modes are a more useful basis for the study of light propagation in stereoisomers.

Incoherent radiation

In nature, electromagnetic radiation is often produced by a large number of individual radiators, producing waves independently of each other. This type of light is described as **incoherent**. In general there is no single frequency but rather a spectrum of different frequencies present, and even if filtered to an arbitrarily narrow frequency range, there may not be a consistent state of polarization. However, this does not mean that polarization is only a feature of coherent radiation. Incoherent radiation may show statistical correlation between the components of the electric field, which can be interpreted as **partial polarization**. In general it is possible to describe an observed wave field as the sum of a completely incoherent part (no correlations) and a completely polarized part. One may then describe the light in terms of the **degree of polarization**, and the parameters of the polarization ellipse.

Parameterizing polarization

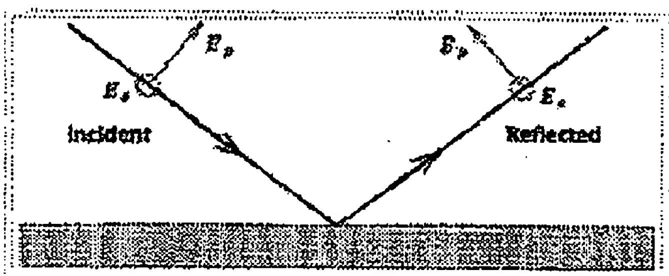
For ease of visualization, polarization states are often specified in te its orientation and elongation. A common parameterization uses the major semi-axis of the ellipse and the x-axis) and the ellipticity, ε (t ellipticity of zero corresponds to linear polarization and an ellipticit The arctangent of the ellipticity, $\chi = \tan^{-1} \varepsilon$ (the "ellipticity angle"), shown in the diagram to the right. An alternative to the ellipticity or however unlike the azimuth angle and ellipticity angle, the latter has terms of the Poincaré sphere (see below).



Full information on a completely polarized state is also provided by two components of the electric field vector in the plane of polarizati show how different states of polarization are possible. The amplitud conveniently represented as a two-dimensional complex vector (the

$$\mathbf{e} = \begin{bmatrix} a_1 e^{i\theta_1} \\ a_2 e^{i\theta_2} \end{bmatrix}.$$

Here a_1 and a_2 denote the amplitude of the wave in the two components of the electric field vector, while θ_1 and θ_2 represent the phases. The product of a Jones vector with a complex number of unit modulus gives a different Jones vector representing the same ellipse, and thus the same state of polarization. The physical electric field, as the real part of the Jones vector, would be altered but the polarization state itself is independent of absolute phase. The basis vectors used to represent the Jones vector need not represent linear polarization states (i.e. be real). In general any two orthogonal states can be used, where an orthogonal vector pair is formally defined as one having a zero inner product. A common choice is left and right circular polarizations, for example to model the different propagation of waves in two such components in circularly birefringent media (see below) or signal paths of coherent detectors sensitive to circular polarization.



Reflection of a plane wave from a surface perpendicular to the page. The p-components of the waves are in the plane of the page, while the s components are perpendicular to it.

Regardless of whether polarization ellipses are represented using geometric parameters or Jones vectors, implicit in the parameterization is the orientation of the coordinate frame. This permits a degree of freedom, namely rotation about the propagation direction. When considering light that is propagating parallel to the surface of the Earth, the terms "horizontal" and "vertical" polarization are often used, with the former being associated with the first component of the Jones vector, or zero azimuth angle. On the other hand, in astronomy the equatorial coordinate system is generally used instead, with the zero azimuth (or position angle, as it is more commonly called in astronomy to avoid confusion with the horizontal coordinate system) corresponding to due north. Another coordinate system frequently used relates to the plane made by the propagation direction and a vector normal to the plane of a reflecting surface. This is known as the *plane of incidence*. The rays in this plane are illustrated in the diagram to the right. The components of the electric field parallel and perpendicular to this plane are termed *p-like* (parallel) and *s-like* (*senkrecht*, German for perpendicular). Light with a p-like electric field is said to be *p-polarized*, *pi-polarized*, *tangential plane polarized*, or is said to be a *transverse-magnetic* (TM) wave. Light with an s-like electric field is *s-polarized*, also known as *sigma-polarized* or *sagittal plane polarized*, or it can be called a *transverse-electric* (TE) wave.

In the case of partially polarized radiation, the Jones vector varies in time and space in a way that differs from the constant rate of phase rotation of monochromatic, purely polarized waves. In this case, the wave field is

likely stochastic, and only statistical information can be gathered about the variations and correlations between components of the electric field. This information is embodied in the **coherency matrix**:

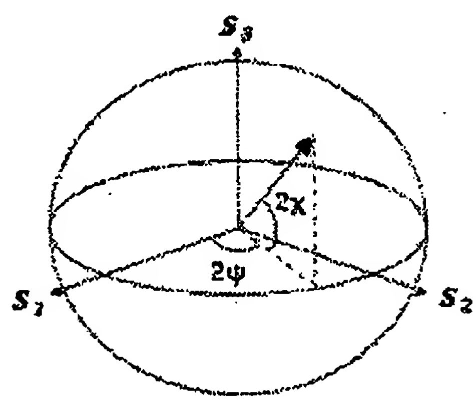
$$\begin{aligned}\Psi &= \langle \mathbf{e}\mathbf{e}^\dagger \rangle \\ &= \left\langle \begin{bmatrix} e_1 e_1 & e_1 e_2^* \\ e_2 e_1^* & e_2 e_2 \end{bmatrix} \right\rangle \\ &= \left\langle \begin{bmatrix} a_1^2 & a_1 a_2 e^{i(\theta_1-\theta_2)} \\ a_1 a_2 e^{-i(\theta_1-\theta_2)} & a_2^2 \end{bmatrix} \right\rangle\end{aligned}$$

where angular brackets denote averaging over many wave cycles. Several variants of the coherency matrix have been proposed: the Wiener coherency matrix and the spectral coherency matrix of Richard Barakat measure the coherence of a spectral decomposition of the signal, while the Wolf coherency matrix averages over all time/frequencies.

The coherency matrix contains all of the information on polarization that is obtainable using second order statistics. It can be decomposed into the sum of two idempotent matrices, corresponding to the eigenvectors of the coherency matrix, each representing a polarization state that is orthogonal to the other. An alternative decomposition is into completely polarized (zero determinant) and unpolarized (scaled identity matrix) components. In either case, the operation of summing the components corresponds to the incoherent superposition of waves from the two components. The latter case gives rise to the concept of the "degree of polarization", i.e. the fraction of the total intensity contributed by the completely polarized component.

The coherency matrix is not easy to visualize, and it is therefore common to describe incoherent or partially polarized radiation in terms of its total intensity (I), (fractional) degree of polarization (p), and the shape parameters of the polarization ellipse. An alternative and mathematically convenient description is given by the Stokes parameters, introduced by George Gabriel Stokes in 1852. The relationship of the Stokes parameters to intensity and polarization ellipse parameters is shown in the equations and figure below.

$$S_0 = I$$
$$S_1 = Ip\cos 2\psi \cos 2\chi$$
$$S_2 = Ip\sin 2\psi \cos 2\chi$$
$$S_3 = Ip\sin 2\chi$$



Here Ip, 2ψ and 2χ are the spherical coordinates of the polarization state in the three-dimensional space of the last three Stokes parameters. Note the factors of two before ψ and χ corresponding respectively to the facts that any polarization ellipse is indistinguishable from one rotated by 180°, or one with the semi-axis lengths swapped accompanied by a 90° rotation. The Stokes parameters are sometimes denoted I, Q, U and V.

The Stokes parameters contain all of the information of the coherency matrix, and are related to it linearly by means of the identity matrix plus the three Pauli matrices:

$$\Psi = \frac{1}{2}\sum_{j=0}^{3} S_j\sigma_j, \text{ where}$$

$$\sigma_0 = \begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} \quad \sigma_1 = \begin{bmatrix}1 & 0\\ 0 & -1\end{bmatrix}$$

$$\sigma_2 = \begin{bmatrix}0 & 1\\ 1 & 0\end{bmatrix} \quad \sigma_3 = \begin{bmatrix}0 & -i\\ i & 0\end{bmatrix}$$

Mathematically, the factor of two relating physical angles to their counterparts in Stokes space derives from the use of second-order moments and correlations, and incorporates the loss of information due to absolute phase invariance.

The figure above makes use of a convenient representation of the last three Stokes parameters as components in a three-dimensional vector space. This space is closely related to the **Poincaré sphere**, which is the spherical surface occupied by completely polarized states in the space of the vector

$$\mathbf{u} = \frac{1}{S_0}\begin{bmatrix}S_1\\ S_2\\ S_3\end{bmatrix}.$$

All four Stokes parameters can also be combined into the four-dimensional Stokes vector, which can be interpreted as four-vectors of Minkowski space. In this case, all physically realizable polarization states correspond to time-like, future-directed vectors.

Propagation, reflection and scattering

In a vacuum, the components of the electric field propagate at the speed of light, so that the phase of the wave varies in space in time while the polarization state does not. That is:

$$\mathbf{e}(z + \Delta z, t + \Delta t) = \mathbf{e}(z, t)e^{ik(c\Delta t - \Delta z)},$$

where k is the wavenumber and positive z is the direction of propagation. As noted above, the physical electric vector is the real part of the Jones vector. When electromagnetic waves interact with matter, their propagation is altered. If this depends on the polarization states of the waves, then their polarization may also be altered.

In many types of media, electromagnetic waves may be decomposed into two orthogonal components that encounter different propagation effects. A similar situation occurs in the signal processing paths of detection systems that record the electric field directly. Such effects are most easily characterized in the form of a complex 2×2 transformation matrix called the Jones matrix:

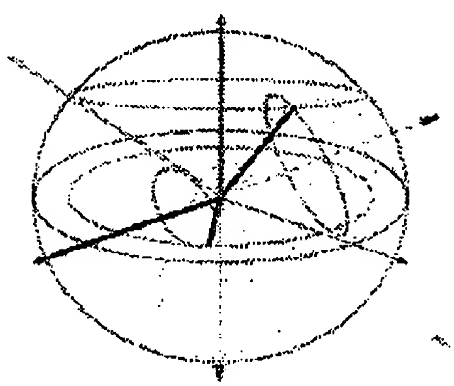
$$\mathbf{e}' = \mathbf{J}\mathbf{e}.$$

In general the Jones matrix of a medium depends on the frequency of the waves.

For propagation effects in two orthogonal modes, the Jones matrix can be written as:

$$\mathbf{J} = \mathbf{T}\begin{bmatrix} g_1 & 0 \\ 0 & g_2 \end{bmatrix}\mathbf{T}^{-1},$$

where g_1 and g_2 are complex numbers representing the change in amplitude and phase caused in each of the two propagation modes, and T is a unitary matrix representing a change of basis from these propagation modes to the linear system used for the Jones vectors. For those media in which the amplitudes are unchanged but a differential phase delay occurs, the Jones matrix is unitary, while those affecting amplitude without phase have Hermitian Jones matrices. In fact, since *any* matrix may be written as the product of unitary and positive Hermitian matrices, any sequence of linear propagation effects, no matter how complex, can be written as the a product of these two basic types of transformations.



Paths taken by vectors in the Poincaré sphere under birefringence. The propagation modes (=rotation axes) are shown with red, blue and yellow lines, the initial vectors by thick black lines, and the paths they take by colored ellipses (which represent circles in three dimensions).

Media in which the two modes accrue a differential delay are called **birefringent**. Well known manifestations of this effect appear in optical wave **plates/retarders** (linear modes) and in **Faraday rotation/optical rotation** (circular modes). An easily visualized example is one where the propagation modes are linear, and the incoming radiation is linearly polarized at a 45° angle to the modes. As the phase difference starts to appear, the polarization becomes elliptical, eventually changing to purely circular polarization (90° phase difference), then to elliptical and eventually linear polarization (180° phase) with an azimuth angle perpendicular to the original direction, then through circular again (270° phase), then elliptical with the original azimuth angle, and finally back to the original linearly polarized state (360° phase) where the cycle begins anew. In general the situation is more complicated and can be characterized as a rotation in the Poincaré sphere about the axis defined by the propagation modes (this is a consequence of the isomorphism of SU(2) with SO(3)). Examples for linear (blue), circular (red) and elliptical (yellow) birefringence are shown in the figure on the left. The total intensity and degree of polarization are unaffected. If the path length in the birefringent medium is sufficient, plane waves will exit the material with a significantly different propagation direction, due to refraction. For example, this is the case with macroscopic crystals of calcite, which present the viewer with two offset, orthogonally polarized images of whatever is viewed through them. It was this effect that provided the first discovery of polarization, by Erasmus Bartholinus in 1669. In addition, the phase shift, and thus the change in polarization state, is usually frequency dependent, which, in combination with dichroism, often gives rise to bright colors and rainbow-like effects.

Media in which the amplitude of waves propagating in one of the modes is reduced are called **dichroic**. Devices that block nearly all of the radiation in one mode are known as **polarizing filters** or simply "polarizers". In terms of the Stokes parameters, the total intensity is reduced while vectors in the Poincaré sphere are "dragged" towards the direction of the favored mode. Mathematically, under the treatment of the Stokes parameters as a Minkowski 4-vector, the transformation is a scaled Lorentz boost (due to the isomorphism of SL(2,C) and the restricted Lorentz group, SO(3,1)). Just as the Lorentz transformation preserves the proper time, the quantity $\det \Psi = S_0^2 - S_1^2 - S_2^2 - S_3^2$ is invariant within a multiplicative scalar constant under Jones matrix transformations (dichroic and/or birefringent).

In birefringent and dichroic media, in addition to writing a Jones matrix for the net effect of passing through a particular path in a given medium, the evolution of the polarization state along that path can be characterized as the (matrix) product of an infinite series of infinitesimal steps, each operating on the state produced by all earlier matrices. In a uniform medium each step is the same, and one may write

$$\mathbf{J} = Je^{\mathbf{D}},$$

where J is an overall (real) gain/loss factor. Here **D** is a traceless matrix such that α**D**e gives the derivative of **e** with respect to z. If **D** is Hermitian the effect is dichroism, while a unitary matrix models birefringence. The matrix **D** can be expressed as a linear combination of the Pauli matrices, where real coefficients give Hermitian matrices and imaginary coefficients give unitary matrices. The Jones matrix in each case may therefore be written with the convenient construction:

$$\mathbf{J_b} = J_b e^{\beta\sigma\cdot\hat{\mathbf{n}}}$$

$$\mathbf{J_r} = J_r e^{\phi i\sigma\cdot\hat{\mathbf{m}}},$$

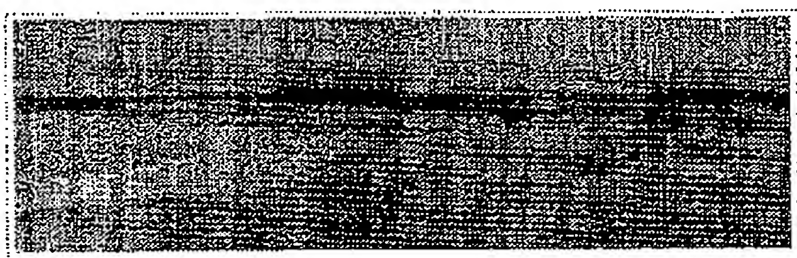
where σ is a 3-vector composed of the Pauli matrices (used here as generators for the Lie group SL(2,C)) and **n** and **m** are real 3-vectors on the Poincaré sphere corresponding to one of the propagation modes of the medium. The effects in that space correspond to a Lorentz boost of velocity parameter 2β along the given direction, or a rotation of angle 2φ about the given axis. These transformations may also be written as biquaternions (quaternions with complex elements), where the elements are related to the Jones matrix in the same way that the Stokes parameters are related to the coherency matrix. They may then be applied in pre- and post-multiplication to the quaternion representation of the coherency matrix, with the usual exploitation of the quaternion exponential for performing rotations and boosts taking a form equivalent to the matrix exponential equations above (*See: Quaternion rotation*).

In addition to birefringence and dichroism in extended media, polarization effects describable using Jones matrices can also occur at (reflective) interface between two materials of different refractive index. These effects are treated by the Fresnel equations. Part of the wave is transmitted and part is reflected, with the ratio depending on angle of incidence and the angle of refraction. In addition, if the plane of the reflecting surface is not aligned with the plane of propagation of the wave, the polarization of the two parts is altered. In general, the Jones matrices of the reflection and transmission are real and diagonal, making the effect similar to that of a simple linear polarizer. For unpolarized light striking a surface at a certain optimum angle of incidence known as Brewster's angle, the reflected wave will be completely *s*-polarized.

Certain effects do not produce linear transformations of the Jones vector, and thus cannot be described with (constant) Jones matrices. For these cases it is usual instead to use a 4×4 matrix that acts upon the Stokes 4-vector. Such matrices were first used by Paul Soleillet in 1929, although they have come to be known as Mueller matrices. While every Jones matrix has a Mueller matrix, the reverse is not true. Mueller matrices are frequently used to study the effects of the scattering of waves from complex surfaces or ensembles of particles.

Polarization in nature, science, and technology

Polarization effects in everyday life



Effect of a polarizer on reflection from mud flats. In the first picture, the

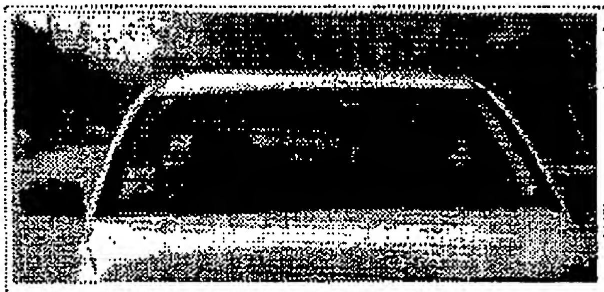
Light reflected by shiny transparent materials is partly or fully polarized, except when the light is normal to the surface. A polarizing filter, such as a pair of polarizing sunglasses, can be used to observe this by rotating the filter while looking through. At certain angles, the reflected light will be reduced or eliminated. Polarizing filters remove

light polarized at 90° to the filter's polarization axis. If two polarizers are placed atop one another at 90° angles to one another, no light passes through.

polarizer is rotated to minimize the effect; in the second it is rotated 90° to maximize it: almost all reflected sunlight is eliminated.

The effects of a polarizer on the sky in a color photograph. The right picture has the polarizer, the left does not. Although some photographic polarizers are called *circular* polarizers because they emit circularly polarized light, they select a linear polarization state from the scene.

Polarization by scattering is observed as light passes through the atmosphere. The scattered light produces the brightness and color in clear skies. This partial polarization of scattered light can be used to darken the sky in photographs, increasing the contrast. This effect is easiest to observe at sunset, on the horizon at a 90° angle from the setting sun. Another easily observed effect is the drastic reduction in brightness of images of the sky and clouds reflected from horizontal surfaces, which is the main reason polarizing filters are often used in sunglasses. Also frequently visible through polarizing sunglasses are rainbow-like patterns caused by color-dependent birefringent effects, for example in toughened glass (e.g. car windows) or items made from transparent plastics. The role played by polarization in the operation of liquid crystal displays (LCDs) is also frequently apparent to the wearer of polarizing sunglasses, which may reduce the contrast or even make the display unreadable.



A view through polarized sunglasses

The photograph at the right was taken through polarizing sunglasses and through the rear window of a car. Light from the sky is reflected by the windshield of the other car at an angle, making it mostly horizontally polarized. The rear window is made of tempered glass. Stress in the glass, left from its heat treatment, causes it to alter the polarization of light passing through it, like a wave plate. Without this effect, the sunglasses would block the horizontally polarized light reflected from the other car's window. The stress in the rear window, however, changes some of the horizontally polarized light into vertically polarized light that can pass through the glasses. As a result, the regular pattern of the heat treatment becomes visible.

Biology

Many animals are apparently capable of perceiving the polarization of light, which is generally used for navigational purposes, since the linear polarization of sky light is always perpendicular to the direction of the sun. This ability is very common among the insects, including bees, which use this information to orient their communicative dances. Polarization sensitivity has also been observed in species of octopus, squid, cuttlefish, and mantis shrimp. The rapidly changing, vividly colored skin patterns of cuttlefish, used for communication, also incorporate polarization patterns, and mantis shrimp are known to have polarization selective reflective tissue. Sky polarization was thought to be perceived by pigeons, which was assumed to be one of their aids in homing, but research indicates this is a popular myth.[1]

The naked human eye is weakly sensitive to polarization, without the need for intervening filters. Polarized

light creates a very faint pattern near the center of the visual field, called Haidinger's brush. This pattern is very difficult to see, but with practice one can learn to detect polarized light with the naked eye.

Geology

The property of (linear) birefringence is widespread in crystalline minerals, and indeed was pivotal in the initial discovery of polarization. In mineralogy, this property is frequently exploited using polarization microscopes, for the purpose of identifying minerals. See pleochroism.

Chemistry

Polarization is principally of importance in chemistry due to the circular dichroism and "optical rotation" (circular birefringence) exhibited by optically active (chiral) molecules. It may be measured using a polarimeter.

Astronomy

In many areas of astronomy, the study of polarized electromagnetic radiation from outer space is of great importance. Although not usually a factor in the thermal radiation of stars, polarization is also present in radiation from coherent astronomical sources (e.g. hydroxyl or methanol masers), and incoherent sources such as the large radio lobes in active galaxies, and pulsar radio radiation (which may, it is speculated, sometimes be coherent), and is also imposed upon starlight by scattering from interstellar dust. Apart from providing information on sources of radiation and scattering, polarization also probes the interstellar magnetic field via Faraday rotation. The polarization of the cosmic microwave background is being used to study the physics of the very early universe. Synchrotron radiation is highly polarised.

Technology

Technological applications of polarization are extremely widespread. Perhaps the most commonly-encountered examples are liquid crystal displays and polarized sunglasses.

All radio transmitting and receiving antennas are intrinsically polarized, special use of which is made in radar. Most antennas radiate either horizontal, vertical or circular polarization although eliptical polarization also exists. The electric field or E-plane determines the polarization or orientation of the radio wave. Vertical polarization is most often used when it is desired to radiate a radio signal in all directions such as widely distributed mobile units. AM and FM radio uses vertical polarization. Television uses horizontal polarization. Alternating vertical and horizontal polarization is used on satellite communications (including television satellites), to reduce interference between programs on the same frequency band transmitted from adjacent satellites (one uses vertical, the next horizontal, and so on), allowing for reduced angular separation between the satellites.

In engineering, the relationship between strain and birefringence motivates the use of polarization in characterizing the distribution of stress and strain in prototypes. Electronically controlled birefringent devices are used in combination with polarizing filters as modulators in fiber optics. Polarizing filters are also used in photography. They can deepen the color of a blue sky and eliminate reflections from windows and standing water.

Sky polarization has been exploited in the "sky compass", which was used in the 1950s when navigating near the poles of the Earth's magnetic field when neither the sun nor stars were visible (e.g. under daytime cloud or twilight). It has been suggested, controversially, that the Vikings exploited a similar device (the "sunstone") in their extensive expeditions across the North Atlantic in the 9th - 11th centuries, before the arrival of the magnetic compass in Europe in the 12th century. Related to the sky compass is the "polar clock", invented by Charles Wheatstone in the late 19th century.

Polarization is also used for some 3D movies, in which the two images for the two eyes are polarized differently, and special filter glasses are used to only present the correct image to the correct eye.

Art

Several visual artists have worked with polarized light and birefringent materials to create colorful, sometimes changing images. Most notable is contemporary artist Austine Wood Comarow who has trademarked her work "Polage." By cutting out numerous small pieces of birefringent films such as cellophane and laminating them onto a sheet of plane polarizing filter, Austine creates both interactive works and motorized kinetic images. Examples of her work are exhibited at the Museum of Science, Boston, the New Mexico Museum of Natural History, Albuquerque and la Cité des Sciences et de l'Industrie, Paris, France.

Other examples of polarization

- Shear waves in elastic materials exhibit polarization. These effects are studied as part of the field of seismology, where horizontal and vertical polarizations are termed SH and SV, respectively.

See also

- Antennas
- Birefringence
- Circular dichroism
- Electromagnetic radiation
- E-plane and H-plane
- Fresnel equations
- Nicol prism
- Optics
- Photon polarization
- Satellite dish

Notes and references

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- *Fundamentals of polarized light : a statistical optics approach*, C. Brosseau, Wiley, 1998, ISBN 0-471-14302-2.
- *Field Guide to Polarization*, Edward Collett, SPIE Field Guides vol. FG05, SPIE, 2005, ISBN 0-8194-5868-6.
- *Polarization Optics in Telecommunications*, Jay N. Damask, Springer 2004, ISBN 0-387-22493-9.
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1. ^ "No evidence for polarization sensitivity in the pigeon electroretinogram", J. J. Vos Hzn, M. A. J. M. Coemans & J. F. W. Nuboer, *The Journal of Experimental Biology*, 1995.

External links

- polarization.com (http://www.polarization.com/): Polarized Light in Nature and Technology
- Polarized Light Digital Image Gallery (http://micro.magnet.fsu.edu/primer/techniques/polarized/gallery/index.html): Microscopic images

made using polarization effects
- Polarization by the University of Colorado Physics 2000 (http://www.colorado.edu/physics/2000/polarization/index.html): Animated explanation of polarization
- The relationship between photon spin and polarization (http://www.mathpages.com/rr/s9-04/9-04.htm)
- A virtual polarization microscope (http://gerdbreitenbach.de/crystal/crystal.html)
- Polarization angle in satellite dishes (http://www.satsig.net/polangle.htm).
- Using polarizers in photography (http://www.bobatkins.com/photography/tutorials/polarizers.html)
- Molecular Expressions: Science, Optics and You - Polarization of Light (http://micro.magnet.fsu.edu/primer/java/scienceopticsu/polarizedlight/filters/): Interactive Java tutorial

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